Five-Year Outlook for Storage Ring Upgrades

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In this note, we briefly discuss possible APS upgrades that may occur in the next five years. We discuss only those options that do not require reduction in scheduled operation.

Global Long Straight Sections: Lengthening all or most of the straight sections (SS) is a practical possibility. The most straightforward option increases the SS length by 2.9 m, with reduced optics flexibility. This is similar to the first stage of ESRF's plan [1]. A more involved and challenging option is to shorten the dipole magnets and quadrupole magnets [2, 3]. In this case, the SS length increases by 3.57 m, while we retain the nominal flexibility of quadrupole triplets on each side of the SS. The effective emittance will be in the range of 3.5 to 4.0 nm for both options.

Sector-by-sector customization. Many sector-by-sector customizations are nominally possible. These include long SS (up to 6 m longer)[4]; reduced horizontal beamsize, e.g., 120 μm [5] or perhaps as low as 40 μm [6] ; higher-energy dipole radiation [7]; and split dipoles to accommodate extra IDs [8]. The risk of is increased emittance, poor lifetime, and poor injection efficiency. Careful planning and study of the combined options is needed to ensure that performance of the APS is not compromised.

Canted devices. Canting insertion devices [9] in more sectors will have essentially no impact on operations. Increased (>1 mrad) canting angle is possible but requires upgraded corrector magnets [10].

Improved coupling control and/or smaller vertical emittance. Some beamlines are sensitive to the vertical emittance and x-y tilt. Improved control of this requires additional skew quadrupoles and/or a method for compensating for decreased lifetime. One option is to install skew quadrupoles in long straights as part of a long SS upgrade. Another is to convert/augment some existing steering magnets with skew quadrupole fields, either globally or in a coupling bump[11].

Higher current. The storage ring is capable of storing significantly higher current than the 100 mA presently used for operations. Operation at 200 mA in 324-bunch mode or 160 mA in 24-bunch mode is feasible [12] within a five-year time frame, provided beamlines and front-ends are upgraded. Operation in hybrid mode at 200 mA with 16 mA in the singlet should also be possible. Faster top-up will almost certainly be needed, although lifetime improvements may mitigate this concern.

New bunch patterns. New bunch patterns have been explored in the past and could be envisioned with the next five years. For example, changing from 24-bunch to 18- or 12-bunch operation might be advantageous, but is not possible now due (mostly) to rf cavity damper issues. A modified hybrid mode is also under development that would provide three "super-bunches" instead of the 56-bunch train [13].

Improved bunch purity. Although not trivial in combination with top-up, a storage ring bunch cleaning system could be developed that would remove beam from nearby buckets (i.e., ± 1 through ± 3 buckets). Possible techniques are gated rf knock-out [14] or use of a bunch-by-bunch feedback system.

Short x-ray pulses. Use of Zholents' crab cavity scheme[15] for producing short pulses has been extensively studied. It should be possible to provide under 2 ps FWHM pulses of 10 keV (or higher) x-rays with 1% of nominal intensity to a few beamlines [16]. Impact on other users is expected to be minimal.

Lifetime improvement. Since APS uses top-up mode most of the time, we are relatively insensitive to lifetime. However, longer lifetime means less-frequent top-up and reduced radiation damage. We could also offset lifetime decreases due to other desired changes, e.g., higher current operation, new bunch patterns, or modified lattices. Lifetime improvement probably requires lower chromaticity, which should be possible with a transverse bunch-by-bunch feedback system; a prototype is now under development.

Quieter top-up. Some of the modification discussed above may lead to shorter lifetime, which can be mitigated using faster top-up. Ideally, top-up should be made transparent to users. One approach is to move all the injection hardware to a single long straight section. A new approach[17] is to use pulsed sextupole magnets, although this seems to be challenging given the large emittance from the APS booster. Upgrading the realtime orbit feedback system will also help suppress top-up related orbit transients.

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Beam Stabilization Project Planning, FY08 - FY12 - Synopsis

Glenn Decker, July 2008

In October of 2005, a white paper entitled “Five-year plan for APS beam stabilization” was put forward by John Carwardine, Frank Lenkszus, Glenn Decker, and Om Singh. This paper enumerated specific goals and an upgrade path aimed at achieving these goals in a 5-year time frame. Since that time, a number of projects recommended in the white paper have been at least partially funded, while others were deferred. At the time it was written, the white paper asserted that “the APS no longer provides the best orbit stability amongst the three large third-generation light source worldwide”. In the case of SPring-8, the focus has been on the passive elimination of beam disturbances which has resulted in vertical rms motion 40% lower than the APS in at least one instance. At ESRF, a new fast global orbit feedback system was commissioned in 2004, resulting in closed-loop bandwidth extending up to 150 Hz, compared with the aging APS system which has a bandwidth of about 60 Hz. As a result, rms noise at ESRF is a factor of 2 or more lower than at APS, in the frequency band from 0.1 to 200 Hz. Shown in Table 1 is a comparison of AC performance between the three facilities.

Table 1: RMS Beam Motion, 0.1-200 Hz

	APS 2008	ESRF c. 2005	SPring-8 c. 2004
Horizontal (μm)	**4.8**	**1.2 - 2.2**	**3 - 4**
Vertical (μm)	**1.6**	**0.8 - 1.2**	**1**

While the APS is lagging in the area of AC orbit stability, it is the only facility of the three which takes advantage of insertion device photon beam position monitors on a large scale. As a result, a majority of APS insertion device beamlines enjoy long-term pointing stability better than 0.6 microradians peak-to-peak over a 24-hour period. One of the challenges articulated in 2005 was to extend this level of long-term stability to the one-week time scale, including reproducibility following machine studies periods. Shown in Table 2 are the beam stability goals quoted from the October 2005 white paper.

Table 2: APS Beam Stability Goals

	AC Motion, 0.1 - 200 Hz		Long-term Drift, (One week)	
	microns rms	**μrad rms**	**microns p--p**	**μrad p-p**
Horizontal	**3.0**	**0.53**	**5.0**	**1.0**
Vertical	**0.42**	**0.22**	**1.0**	**0.5**

It is hoped that with sufficient application of resources the above-stated goals can be comfortably met within the next five years. A series of nine subprojects have been proposed to address present conditions limiting our ability to stabilize the beam. Several of them have developed to the point that large-scale deployment can begin within the next 12 to 18 months, while others will require significant development work to finalize upgrade plans.

Front End Development for APS Renewal Over the Next Five Years

APS was originally built with standard front ends (version. 1.2) for each of the original twenty sectors. Over the years, new designs were created for specific purposes: version 1.5 undulator only front end for higher stored beam current, canted undulator configuration (CU) and High Heat Load (HHL) for dual collinear undulators. As APS evolves, new designs will be developed for specialized insertion devices and experiments. The driving factors for new designs are the total power of the x-ray beam from the chosen insertion devices, the power density at the location of masks and absorbers, the horizontal separation and vertical divergence of the x-ray fan(s) and the desired front end exit opening aperture (windowed or windowless). A number of new front end designs for beamlines currently under design or consideration will be developed over the next 5 years. These include the front end for the IEX beamline at sector 29, a specialized front end for superconducting crab cavities for picosecond timing, and a front end for a short-period superconducting undulator. All new front end designs will be required to be able to absorb the x-ray thermal load from up to 200 mA of stored beam. One mrad separation for canted beams will remain the practical limit without substantial modification of the storage ring. Some ability to accommodate higher x-ray thermal loads than current designs may be possible. R &D to develop new materials and methods of dissipating these thermal loads is ongoing.

Science teams anticipating requirements that diverge from the standard capabilities of current generation front ends are encouraged to contact Patric Den Hartog, Mechanical Engineering and Design Group Leader, to discuss their needs.

Thermal Capacity of Current Designs for APS Front Ends

FE Type	Total Power (kW)	Power Density (kW/mrad^2)
Version 1.2	6.9	198
Version 1.5	8.9	245
CU	20	281
HHL	21	590

Insertion Devices

The focus on insertion devices for beamlines has shifted away from building many copies of a standard multi-purpose undulator towards providing devices that are customized to best meet the needs of the research being done on the particular beamline. Planar undulators with a variety of new period lengths have been designed, built, and installed. The period lengths were chosen in consultation with the beamline users to maximize the brilliance in the particular tuning range of interest. New undulators with either existing or new period lengths can be designed and built as needed.

Other characteristics of the undulators can also be adjusted to suit the needs of beamlines. Work is underway on a polarizing undulator for the IEX beamline. While variable polarization of the x-rays produced would be of interest to other beamlines, here it is chosen because of the absence, on beam axis, of photons with higher harmonic energies. The undulator for IEX may also be quasiperiodic and capable of producing linear polarization. The quasiperiodicity is sought here because, although it reduces the brilliance in the first harmonic, it shifts the higher harmonics in energy so they don't make it through the monochromator. The loss in higher-harmonic contamination and the resulting improvement in the experimental signal-to-noise ratio more than make up for the loss in brilliance. Other users have also expressed interest in undulators with reduced higher harmonics.

Work is also underway on a superconducting undulator. Some users are interested in high-energy photons and want high brilliance. This can be achieved with shorter period undulators, but as the period length gets short the achievable field strength on axis decreases, decreasing the tuning range of the undulator. A short-period superconducting undulator can produce a stronger magnetic field than a permanent-magnet undulator with the same period length, making the additional brilliance from a shorter period feasible. The superconducting undulator as presently designed will produce first-harmonic x-rays in the 20-25 keV range.

Longer straight sections that allow either longer or additional undulators are also a possibility. Additional in-line undulators allow the possibility of customizing one undulator for a particular purpose without losing the flexibility that is provided by another. Also, the sector can be canted, when a bend is imposed on the beam between undulators so that two separate x-ray beams result, one from each undulator. Two separate beamlines at a relative angle of ~1 mrad can then be built and operate separately in the same sector.

Other specialized undulators could be developed to meet particular user needs. Users with other requirements are invited to discuss their needs with the Magnetic Devices Group. Contact the MD group leader, Liz Moog, at moog@aps.anl.gov .